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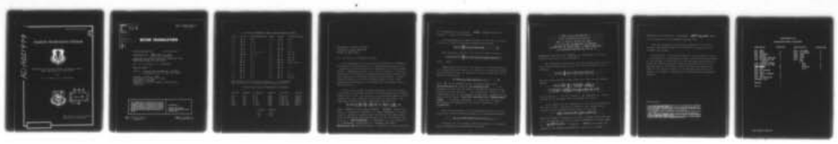

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BEHAVIOR OF A MILDLY SLOPING CYLINDRICAL PANEL
UNDER THE EFFECT OF WIND GUSTS

by

A. S. Vol'mir, A. F. Danilenko

FOREIGN TECHNOLOGY DIVISION

EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

BEHAVIOR OF A MILDLY SLOPING
CYLINDRICAL PANEL UNDER THE
EFFECT OF WIND GUSTS

A.S. Vol'mir, A.F. Danilenko (Moscow)

The investigation of the forced oscillations of elements of structures under the effect of a pulsating wind pressure is of interest in connection with the possibility of their fatigue failure. Examined in works [1, 2, 3] and a number of others is the behavior of flexible one-dimensional structures under a wind load treated as a stationary Gaussian random process. Using a similar approach, we find the average squares of the normal movements and stresses of a two-dimensional structure, which is what a shell is.

Let us take a mildly sloping cylindrical panel with length a and width b, the edges of which are hinged supported and freely shifted in the plan. Let apply to the curvilinear edges a static compressive load p uniformly distributed over the width. The equations of motion of such a panel have the form [4]

$$\frac{D}{h}\nabla^2\nabla^2 w = \frac{1}{R}\cdot\frac{\partial^2\Phi}{\partial x^2} - p\frac{\partial^2 w}{\partial x^2} - \rho\frac{\partial^2 w}{\partial t^2} + \frac{q(t)}{h}; \quad (1) \qquad \frac{\nabla^2\nabla^2\Phi}{E} = -\frac{1}{R}\cdot\frac{\partial^2 w}{\partial x^2}, \quad (2)$$

where $w(x, y, t)$ is the normal movement; $\Phi(x, y, t)$ - stress function; D - cylindrical rigidity; E - elastic modulus; ρ - density; R and h - radius of curvature and thickness of the panel; mean value of the random time function $q(t) = 0$ and the spectral density [3] $S_q(\omega) = (\rho_0 C_0 V_0)^2 S_v(\omega)$; ω - frequency; ρ_0 - air density; C_0 - aerodynamic coefficient; V_0 - average wind speed; $S_v(\omega) = 2\sigma^2 L/\pi V_0 (1+\tilde{\omega}^2)$ - spectral density of pulsations of wind speed [5];

σ^2 - dispersion of wind speed; $\omega = \omega L/V_0$ - dimensionless frequency; L - scale of turbulence.

Let approximate the normal movement in the form of a decomposition by forms of the free sustained oscillations

$$w(x, y, t) = \sum_{1}^{m,n} f_{mn}(t) \sin(m\pi x/a) \sin(n\pi y/b). \quad (3)$$

From equations (2) and (3) we find the stress function

$$\Phi(x, y, t) = E a^2 \pi^{-2} R^{-1} \sum_{1}^{m,n} m^2 (m^2 + n^2\lambda^2)^{-2} f_{mn}(t) \sin(m\pi x/a) \sin(n\pi y/b) - py^2/2, \quad (4)$$

where $\lambda = a/b$.

Substituting (3) and (4) into equation (1) and integrating by the Buvnov-Galerkin method, we obtain, by introducing formally the dissipative terms, the equation of force oscillations of the panel in the form [6]

$$\ddot{f}_{mn} + 2\beta_{mn}\omega_{mn}\dot{f}_{mn} + \omega_{mn}^2 f_{mn} = Q_{mn}(t) \quad (m, n = 1, 3, \ldots), \quad (5)$$

where β_{mn} is the damping factor; the generalized forces $Q_{mn}(t) = 16q(t)/\pi^2 \rho h m n \quad (m, \quad n = 1, 3, \ldots)$; $\omega_{mn} = (\pi ch/ab)\left(\overset{*}{p}_{\text{в}\,mn} - \overset{*}{p}_m\right)^{0.5}$ - the frequency of the m and nth form of oscillations taking the compressive load into account; c - the propagation velocity of the longitudinal waves in the material of the panel; parameter of the upper critical stress $\overset{*}{p}_{\text{в}\,mn} = \pi^2 (m^2 + n^2\lambda^2)^2 [12\lambda^2(1-\mu^2)]^{-1} + k^2\lambda^2 m^4[\pi(m^2+n^2\lambda^2)]^{-2}$; $k = b^2/Rh$ - curvature parameter; μ - coefficient of lateral deformation; the parameter of the static compressive load $\overset{*}{p}_m = p b^2 m^2 / E h^2$.

Using the expressions for the generalized forces from (5), we find the relative spectral density of the generalized forces

$$S_{Q_{ij}, Q_{lr}}(\omega) = (16/\pi^2 \rho h)^2 [S_q(\omega) / i j l r] \quad (i, j, l, r = 1, 3, \ldots).$$

Following [6], we determine the mean products of the generalized coordinates and generalized velocities

$$\overline{f_{ij} f_{lr}} = \varkappa_{ijlr} \left(X_{ij} / Y_{ij} + X_{lr} / Y_{lr} + A \right);$$

$$\overline{\dot{f}_{ij} \dot{f}_{lr}} = \varkappa_{ijlr} (V_0 / L)^2 (Z_{ij} / Y_{ij} + Z_{lr} / Y_{lr} - A),$$

when $X_{ij} = \beta_{ij} \left[5 \tilde{\omega}_{ij}^2 - \tilde{\omega}_{lr}^2 + \tilde{\omega}_{ij}^2 \left(7 \tilde{\omega}_{ij}^2 - 3 \tilde{\omega}_{lr}^2 \right) \right];$

$$Y_{ij} = \tilde{\omega}_{ij} \left[\left(\tilde{\omega}_{ij}^2 - \tilde{\omega}_{lr}^2 \right)^2 + \left(4 \beta_{ij} \tilde{\omega}_{ij}^2 \right)^2 \right] \left[\left(\tilde{\omega}_{ij}^2 + 1 \right)^2 + \left(2 \beta_{ij} \tilde{\omega}_{ij}^2 \right)^2 \right];$$

$$Z_{ij} = \beta_{ij} \tilde{\omega}_{ij}^2 \left[3 \tilde{\omega}_{ij}^2 + \tilde{\omega}_{lr}^2 + \tilde{\omega}_{ij}^2 \left(5 \tilde{\omega}_{ij}^2 - \tilde{\omega}_{lr}^2 \right) \right]; \qquad A = \left[\left(\tilde{\omega}_{ij}^2 + 1 \right) \left(\tilde{\omega}_{lr}^2 + 1 \right) \right]^{-1};$$

$$\varkappa_{ijlr} = (16 p_0 \sigma C_0 L^2 / \pi^2 \rho h V_0)^2 \, (i j l r)^{-1} \quad (i, j, l, r = 1, 3, \ldots);$$

X_{lr}, Y_{lr}, Z_{lr} are obtained from X_{ij}, Y_{ij}, Z_{ij} by replacement of the subscripts i by l, j by r and conversely.

The expressions obtained for the mean products make it possible to find jointly from (3) and (4) the mean square of the movements

$$\overline{w^2 (x, y)} = \sum_{1,3\ldots}^{ijlr} \overline{f_{ij} f_{lr}} \sin \frac{i \pi x}{a} \sin \frac{j \pi y}{b} \sin \frac{l \pi x}{a} \sin \frac{r \pi y}{b}$$

and the normal stresses acting along the x axis in the extreme fibers

$$\overline{\sigma_x^2 (x, y)} = \left(\frac{E h}{a^2} \right)^2 \sum_{1,3\ldots}^{ijlr} \left[\pm \frac{\pi^2 (i^2 + \mu j^2 \lambda^2)}{2 (1 - \mu^2)} - \frac{k \lambda^4 i^2 j^2}{(i^2 + j^2 \lambda^2)^2} \right] \times$$

$$\times \left[\pm \frac{\pi^2 (l^2 + \mu r^2 \lambda^2)}{2 (1 - \mu^2)} - \frac{k \lambda^4 l^2 r^2}{(l^2 + r^2 \lambda^2)^2} \right] \overline{f_{ij} f_{lr}} \sin \frac{i \pi x}{a} \sin \frac{j \pi y}{b} \sin \frac{l \pi x}{a} \sin \frac{r \pi y}{b},$$

and according to the Rice formula - the frequency of intersection of the assigned level of movement or stress.

As an example let us investigate in the first approximation the ratio of the standard of stress to the average stress written for the greatest stressed point of the panel

$$\left(\overline{\sigma_x^2} \right)^{0.5} / \bar{\sigma}_x = \left[2 \sigma \bar{\omega}^2 / V_0 \left(\bar{\omega}^2 + 1 \right) \right] \left[\left(\bar{\omega}^2 + 1 \right) / 2 \beta \bar{\omega}^2 + 1 \right]^{0.5}.$$

With an increase in frequency this ratio rapidly grows from zero up to its maximum, and then it slowly approaches the value equal to $\lim_{\omega \to \infty} \left(\overline{\sigma_x^2} \right)^{0.5} / \bar{\sigma}_x = 2 \sigma / V_0.$ Assuming $\sigma \approx 0.1 V_0$, we obtain (the region of low frequencies, where the solution in a linear

formulation is incorrect, is excluded) $\left[\left(\overline{\sigma_x^2}\right)^{0,5} / \bar{\sigma}_x\right]_{\min} \approx 0{,}2\alpha,$ where α is the number of the standards (usually 2-3).

Thus the pulsating stresses are comparable to the static stresses and therefore must be considered in calculations for strength and fatigue.

Undoubtedly, this problem requires a more complete study on the basis of the nonlinear theory. The following approaches to the solution to the problem of the nonlinear oscillations of plates and shells caused by a gusty wind are possible: 1) the approach used in [7] allows solving the nonlinear problem by means of the spectral method; 2) the approach proposed in [8] permits in a number of cases using the Fokker-Planck-Kolmogorov equation.

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